Are we there yet?

The seaweed side of the story.

Benoit Queguineur

Irish Seaweed Research Group
Ryan Institute
Environment, Marine and Energy Research
National University of Ireland, Galway

Aquafuels conference 30th June, 2011

Outline

- History
- AQUAFUELS - A key moment
- AQUAFUELS - Results
- The forces in action (on-going activities)
- A key moment-now
- Recommandations

History

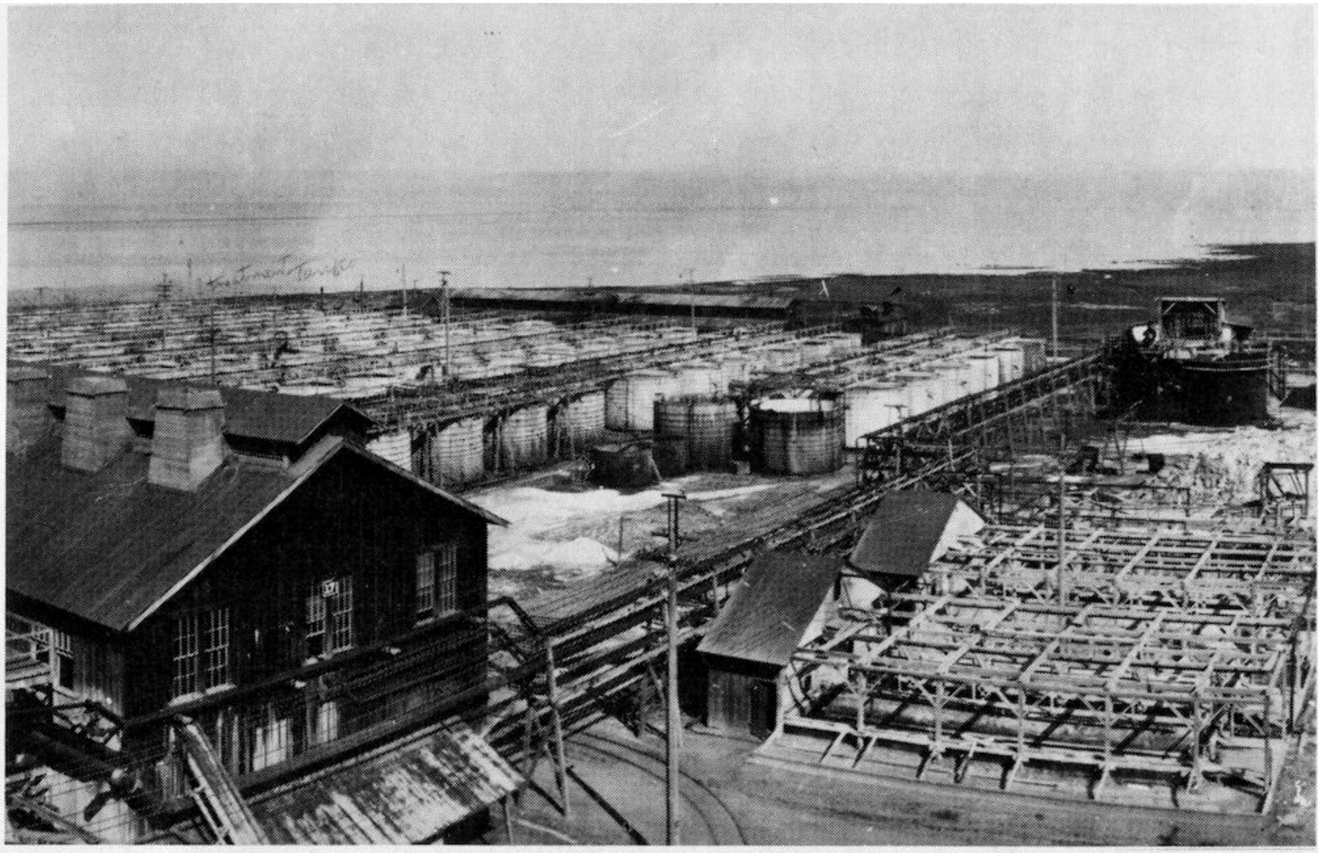


Fig. 2. Early kelp digestion tanks at the Hercules facility. (Photograph courtesy of the San Diego Historical Society).

Bird & Benson 1987. Devel. Aqua. & Fish. Sci 16:285-. 303

History

How large is large? 15,800,000 t FW worth 7,5 Billion$ (FAO, 2008)

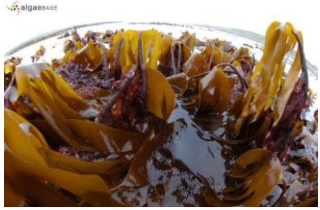
AQUAFUELS – A key moment

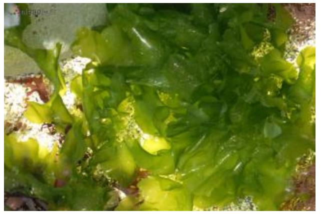
- 1914: Embargo on Chemicals (Neushul, 1987)
  - Energy: OK
  - Environment: OK
- 1970's: Embargo on Energy (Peter, 1987)
  - Energy: Issue
  - Environment: growing issue
- 2010: Aquafuels project AQUAFUELS ALGAE TOWARDS BIOFUELS
- 2011: Embargo on Seafood (Shortage of seaweed)
  - Energy: Issue
  - Environment: Issue
  - Food: growing issue

AQUAFUELS-WP1

- Taxonomy
  - List of species (Phaeophyta/Rhodophyta/Chlorophyta/Other aquatic biomass)
  - Taxonomical description (molecular tools)

    Ex: former *Laminaria saccharina* becomes *Saccharina latissima*
- Biology
  - Chemical content-proximate analysis (relevant to biofuel production)
- Biotechnology
  - Current biotech application
- Mapping (Natural standing stock, Bloom, Cultivation sites)





AQUAFUELS-WP3 sustainability

Focused on biomass production

- Downstream by-products (update from industry), technological bottlenecks.
- LCA, Environmental impact assessment
  - Tank cultivation, Large-scale cultivation (IMTA), Kelp Harvesting, Bloom harvesting
- Economical assessment
  - Large scale cultivation, Bloom harvesting
- Recommandations

The forces in action- European cultivation groups

- Denmark, France (Brittany), Germany, Ireland, Israel, the Netherland, Norway, Portugal, Spain, Sweden, UK (Scotland), Other (Call EABA immediately).

- Species, group, productivity, keywords publication

The forces in action- European cultivation groups

	Location/Season (or culture duration)	Production	Keywords	Econ. eval.	Reference
Land Tank / Pond / Raceway Cultivation					
Palmaria palmata	Germany / Spring	0.5-0.8 mm.day-1 with doubling biomass every 14 days	Cultivation of vegetative thalli; biomass; length; tetrasporangia induction	No	Pang & Luning 2006
Ulva lactuca	Greece (Aegean sea)	9,4 g FW.m-2.day-1 (8 days only) in shallow tanks	Associated with sewage treatment plant. Low salinity, not aimed at biomass production.		Tsagkamilis *et al*. 2010
Land Tank / Pond / Raceway Cultivation: Integrated					
Sparus aurata	Portugal (commercial farm)				
	9 months	63.7 DW.m-2.day-1	GR; Biomass production		Schuenoff *et al.* 2006, Mata *et al.*,2006; Mata *et al.*, 2007
Asparagopsis armata (Falkenbergia rufolanosa)	2 weeks experiment (winter & spring)	43 & 90g DW.m-2.day-1	GR;Biomass production; TAN uptake efficiency; Nitrogen content		
	1 week experiment (winter & spring)	71 & 125g DW.m-2.day-1	GR; Biomass production; Nitrogen content		Mata et al., 2010
Ulva rigida	1 week experiment (winter & spring)	44 & 73g DW.m-2.day-1	GR; Biomass production; Nitrogen content		Mata *et al.*, 2010
Scophthalmus maximus, Dicentrarchus labrax, Solea senegalensis	Portugal (commercial farm)				
Gracilaria vermiculophylla	9 months	23.3g DW.m-2.day-1	GR; Biomass production, Nitrogen content; TAN, nitrate and phosphate uptake efficiency, Agar; Mycosporine like aminoacids	No	Abreu, 2010, Abreu et *al.*, 2011; Pereira *et al.*, 2010; Sousa *et al.*, 2010
Mastocarpus stellatus	2 months (spring)	29.6g DW.m-2.day-1	GR;Biomass production; TAN and Nitrate uptake efficiency	No	Domingues et al. (2011) *unpublished*
Ulva lactuca	Israel	up to 376g FW.m-2.day-1	Biofiltration; fishpond effluents; yield; chemical analysis	No	Msuya & Neori 2008

The forces in action- European cultivation groups

Scophthalmus maximus *Dicentrarchus labrax* *Chondrus crispus* *Gracilaria bursa pastoris* *Palmaria palmata*	Portugal / year round (commercial farm) 1 month experiments (spring & summer) 1 month experiments (summer & autumn) 1 month experiment (spring)	8.4 & 36.6g DW.m-2.day-1 31.2 & 19.5g DW.m-2.day-1 40.2g DW.m-2.day-1	GR; Biomass production; TAN uptake efficiency; Fish feed ingredient (*Gracilaria*)	No	Matos *et al.* 2006; Valente et al., 2006;
Sparus aurata *Ulva rotundata* *Gracilariopsis longissima*	Spain (Andalucia) / Spring	33.6g DW.m-2.day-1 and GR 7.5%.day-1 10.2g DW.m-2.day-1 and GR 6.5%.day-1	Biofiltration; stocking density; yield; biomass evolution; nitrogen; phosphorus	No	Hernandez *et al.* 2005
Sparus aurata *Haliotis discus hannai* *Paracentrotus lividus* *Ulva lactuca*	Israel / Winter-Spring	FCR= 2.66-25 with *Ulva lactuca* 94-117g FW.m-2.day-1	Biofiltration; recirculation; ammonia toxicity	No	Schuenhoff *et al.* 2003
Sparus aurata *Dicentrarchus labrax* *Ulva rotundata*	Portugal / Spring	29g DW.m-2.day-1 and GR 21.8%.day-1	Biofiltration; raceway cultivation; yield	No	Mata & Santos 2001
Sparus aurata *Haliotis discus hannai* *Ulva lactuca* *Gracilaria conferta*	Israel (1 year)	0.67 % GR.day-1 and 28kg.m-2.year-1 0.9% GR.day-1 (juveniles) 0.34% GR.day-1 (young adults) 78kg FW.m-2.year-1 poor yield	Biofiltration; nutrient budget; seaweed yield; abalone growth rate	No	Neori *et al.* 2000
Haliotis tuberculata *Ulva lactuca* *Gracilaria conferta*	Israel	0.26% body weight.day-1 230 g FW.m-2.day-1 highly erratic growth	Biofiltration; nitrogen recycling; pilot scale, modular, land-based system; yield; abalone growth rate	No	Neori *et al.* 1998

The forces in action- European cultivation groups

Sparus aurata *Haliotis tuberculata* *Tapes philippinarum* *Ulva lactuca* *Gracilaria spp.*	Israel / year round	0.3% GR.day-1 FCR=20-25g FW seaweed per gram of abolone produced 250 g FW.m-2.day-1	Theoretical yield & revenue projections; system design	Theoretical	Shpigel & Neori 1996
Sparus aurata *Ulva lactuca*	Israel		Biofiltration; recirculation; water-quality; effluent	No	Neori *et al.* 1996
Sparus aurata *Ulva rigida*	Spain (Canary Islands)	40 g DW.m-2.day-1	Biofiltration; yield; flow rate	No	Jimenez del Rio *et al.* 1996
Oncorhynchus mykiss *Gracilaria tenuistipitata*	sweden (5-6 months)	4-9% GR.day-1	Growth rate; biomass; nutrient uptake	No	Haglund & Pedersen 1993
Sparus aurata *Ulva lactuca*	Israel		Yield; growth rate; marine fishponds	No	Neori *et al.* 1991
Ulva lactuca	Israel	55g DW.m-2.day-1	Biofiltration; growth rate; nitrogen content	No	Vandermeulen & Gordin 1990

The forces in action-
European cultivation groups

Sea Cultivation					
Laminaria saccharina *Laminaria saccharina*	Canada (8months) UK (6 months)	3-8 kg FW.m-1 rope pm 4.2-28.4kg FW.m-1 rope pm	Yield; cultivation methodology		Druehl et al. 1988
Laminaria saccharina *Saccorhiza polyschides* *Alaria esculenta*	Isle of Man/UK	5.6 kg/m rope/y (FW) (extrapolated from kain and dawes 1987)	detached from ropes in strong water movement		Kain (1991)
Laminaria hyperborea *Saccorhiza polyschides*					Dion and Golven (1989)
Undaria pinnatifida			"free-living" gametophytes technique		Perez et al (1984)
Laminaria digitata	Ouessant/France	144 plants/m rope/8 months	Clean small plants for food purposes		Perez (1997)
Alaria esculenta	Ireland	15.6 kg/m/ 5 months	hybridisation experiments		Kraan PhD thesis 2000
Laminaria saccharina	Kiel/Germany	0.5kg FW/m after 3 months	free floating cultures of small plants attached to ropes resulted in larger plants than seeded ropes. Ropes overseeded. Positive effects of L.saccharina culture in the Baltic sea.		CRM trials cited in Werner et al (2004)
Laminaria saccharina	Helgoland/Germany	4kg FW/m/6 months	Ring structure for offshore cultivation		Buck & Buchholz, 2004
Alaria esculenta	Ireland	3-5 kg FW/m rope after 4-5 months	reproducible procedure from fertilisation to offshore cultivation		Arbona 1997
Saccharina latissima	Spain NW	12.7 kg FW.m-1 rope (after 107 days)			Peteiro and Freire (2009)
Undaria pinnatifida	Spain NW	9.6 kg FW.m-1 rope (after 107 days)			Peteiro and Freire (2011)

The forces in action- European cultivation groups

Saccharina latissima	Spain NW	16.1 kg FW.m-1 rope (after 119 days)			Peteiro and Freire (not yet published)
Palmaria palmata	Spain (Asturias)/ Spring (4 weeks)	14%GR.day-1 initial FW, 0.7g FW.day-1	Rope cultivation; bag cultivation; biochemical analysis	No	Martinez *et al.* 2006
Laminaria groenlandica *Laminaria saccharina* *Cymathere triplicata* *Laminaria saccharina* *Laminaria religiosa* *Laminaria japonica* *Laminaria japonica* *Laminaria japonica* *Laminaria diabolica* *Laminaria diabolica* *Alaria esculenta* *Undaria pinnatifida*	Canada (18 months) Canada (8months) Canada (7 months) UK (6 months) korea (5 months) USSR (6 months) China (6 months) Japan (11 months) Japan (20 months) Japan (9 months) UK (3 months) Japan (5 months)	2.6-20.5 kg FW.m-1 rope pm 3-8 kg FW.m-1 rope pm 1.1-2.7 kg FW.m-1 rope pm 4.2-28.4kg FW.m-1 rope pm 6-9 kg FW.m-1 rope pm 10 kg FW.m-1 rope pm 5-20 kg FW.m-1 rope pm 8.4-24 kg FW.m-1 ropepm 10.2-15.9 kg FW.m-1 rope pm 18-24 kg FW.m-1 rope pm 7.2-11.9 kg FW.m-1 rope pm <5-10 kg FW.m-1 rope pm	Yield; cultivation methodology	No	Druehl *et al.* 1988
Sea Cultivation: Integrated					
Salmo salar *Laminaria saccharina* *Laminaria hyperborea* *Saccorhiza polyschides*	Scotland	 10 kg/m2/y (FW) 2 kg/m2/y (FW) 17 kg/m2/y (FW)			Sanderson 2006 PhD
Mytilus edulis *Laminaria saccharina*	Galicia, Spain (4months)	6.2 kg/m-1 rope/ 4 months	decrease in harvestable biomass after 13 months due to loss of plants.		Peteiro et al (2006)
Salmo salar *Laminaria saccharina* *Laminaria digitata* *Alaria esculenta* *Laminaria hyperborea* *Saccorhiza polyschides*	Ireland				Ratcliff (2011) PhD

The forces in action-
European cultivation groups

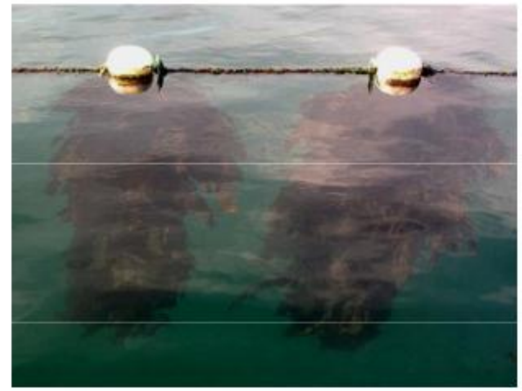
Seaweed Production (commercial or pilot-scale) in Europe, collaboration with research institutes:

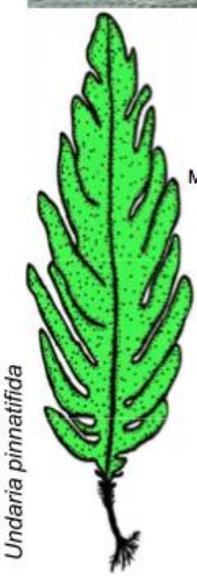
- •Seaweed Energy Solutions: www.seaweedenergysolutions.com
- •Hortimare: www.hortimare.com
- •Ard Toe Marine Laboratory: www.ardtoemarine.co.uk
- •C-weed www.c-weed-aquaculture.com
- •Aleor www.aleor.org
- •Algues et mer *www.algues-et-mer.com*
- •Porto Muiños® A Coruña, Galicia http://www.portomuinos.com
- •Agrogalicia Pontevedra, Galicia http://www.cannori.com/
- •Algas Rias de Aldan Pontevedra, Galicia
- •Other (Call EABA immediately)


Seaweed culture now established in Scotland
Tiny plants 2mm seeded to string
3 months
Each plant at harvest,
6 – 8 months later, 1- 2m
BIOMARA- SAMS Scotland

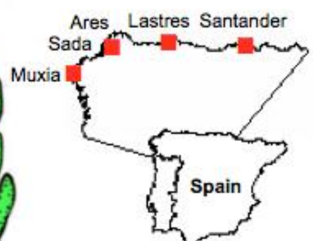
***SEAWEEDS CULTURE: Undaria pinnatifida* ("wakame")**

Experimental cultivation in open sea





Undaria pinnatifida



Culture time at sea	Biomass yield	Source
129 days	9.6 kg wet m^{-1} rope	Peteiro and Freire (2011)

Peteiro C, Freire Ó (2011) Effect of water motion on the cultivation of the commercial seaweed *Undaria pinnatifida in a coastal bay of Galicia, Northwest Spain. Aquaculture 314: 269-276*

Author: César Peteiro, (peteiro@st.ieo.es)
Instituto Español de Oceanografía (IEO), Centro Oceanográfico de Santander

The forces in action- Irish Seaweed Research Group (ex-ISC)

Past experience within the Irish Seaweed Research Group

Strain selection of *Alaria esculenta* – genetic fingerprinting & hybridisation studies (2000)[1]

- Strain hybridisation field experiments of *Alaria esculenta* (2000)[1]
- Pre-commercial cultivation of *Asparagopsis armata* (1998)
- Long-line cultivation of *Palmaria palmata* & *Alaria esculenta* (2001 – Roaring Water Bay Seaweed Co-operative with BIM and Irish Seaweed Centre)[2]
- Tank cultivation of *Ulva sp., Porphyra Sp. & Palmaria palmata*
- *Laminaria hyperborea* biomass and demographics survey (2008)
- *Ascophyllum nodosum* biomass survey (2008/9)

Current Cultivation in the Irish Seaweed Research Group

Seaweed Hatchery

• Optimal hatchery culture conditions for *L. digitata, P. palmata, Porphyra sp.*
• Monitoring and improving the yield of cultured seaweeds on culture rigs at sea sites
• Development of seaweed harvesting strategies

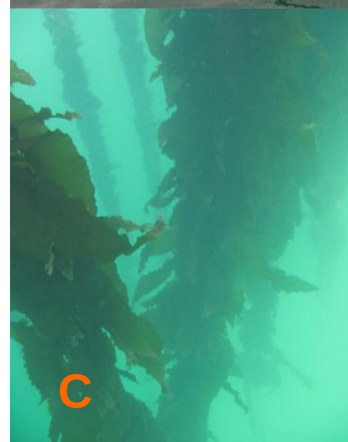
The application of macroalgae as a biofuel feedstock (PhD research)

• Growth and biomass of lab and sea stages (longline cultivation) of the 5 native kelps
• Comparison of growth and quality under IMTA/non-IMTA conditions
• Wild biomass estimation, and review of sustainability and harvesting issues

Energetic Algae

• An integrated network of pilot scale algal facilities to develop and exchange best practice for algal biomass and bioenergy, tailored to prevailing conditions in NWE. Macroalgal cultivation coordinated by ISRG.

Spore and vegetative cultivation of *Porphyra dioica* (MSc research)



A L. digitata on longlines

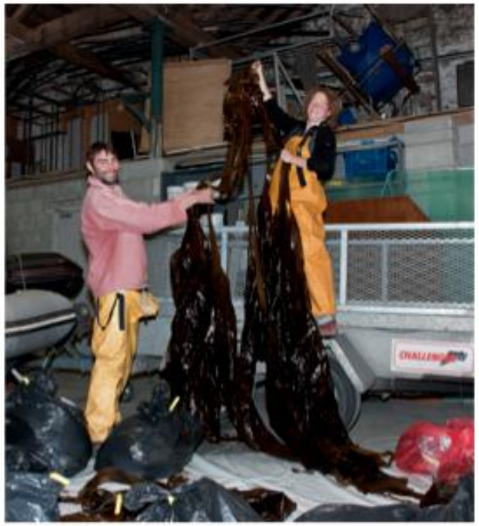
B P. palmata in tanks

C L. digitata growing alongside mussels (background ropes)

D Seaweed longlines next to salmon cages

E Cultivated P. palmata

The forces in action- Irish Seaweed Research Group (ex-ISC)



AQUAFUELS – A key moment

Opportunity to combine a profitable industry to answer the question of Large-scale cultivation in Europe and Environmental Impact, LCA, economic assessment for future Biofuels usage.

Things change because there is a need not because they are economically viable.

AQUAFUELS – Recommendations

Research Gaps:

- **Productivity data at a relevant scale and from different environments**

NO MORE SPECULATION!!! **Phase 1: 10 x 10 ha, plus one 100 ha farm at least! Then scale up.**

- **Begin Strain Selection and Hybridisation trials for yield/quality improvements**

Which species should we concentrate on? Need feedback from conversion/bio-refinery people…

- **Environmental Impact Assessment at a relevant scale and in different environments**

Many, many gaps to fill in in order to make a full EIA possible and relevant.

- **Engineering solutions for moving into higher energy off-shore environments**

Options for technology sharing with other aquaculture sectors that are also moving off-shore.

- **Technical solutions for efficient harvesting and possibilities for storage**

AQUAFUELS – Recommendations

- **MACROALGAE need to be recognised as having potential in the biofuels/biorefinery arena**

i.e. see the recent papers on ALGAL biofuels that have scant, if any, mention of MACROALGAE

- **AVAILABILITY OF DIGESTORS on the shoreline, close to blooming area (Green-red tides)**

- **MACROALGAL CULTIVATION needs to be specifically integrated into aquaculture policies and legislation and recognised *in a different category to fed aquaculture to facilitate integrated aquaculture.***

- **Political support will enable the efficiency and ease of incorporating large-scale cultivation into the existing aquaculture framework IN A WAY THAT IS ENVIRONMENTALLY APPROPRIATE AND ECONOMICALLY BENEFICIAL**

Thanks for your attention!

This project is being funded by the EU Commission within the VII Framework Programme for Research and Development